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(54) **A printer apparatus adapted to reduce cross-talk between ink channels therein and method thereof**

(57) Printer apparatus adapted to reduce cross-talk between ink channels (20a, 20b, 20c) therein and method thereof. The apparatus includes a substrate (180) having a plurality of spaced-apart pairs of selectively actuatable side walls (220, 230) defining respective channels therebetween of different depths (A, B, C). Each channel receives an associated one of a plurality of ink bodies (22) therein and the substrate is formed of piezoelectric material responsive to electric stimuli. The pairs of side walls are preferably separated one from another by means of an intervening cut-out (305) for reducing mechanical coupling between the ink channels. A cover plate (190) is connected to the substrate and has a plurality of orifices (200) therethrough in registration with respective ones of the channels such that the orifices are off-set one from another. Accordingly, in one embodiment of the invention, the channels have differ-

ent depths and, therefore, the orifices, which are in registration with the channels, are off-set one from another to accommodate the different depths of the channels. A selected ink channel, which belongs to a first group of channels having a first predetermined depth, pressurize as its pairs of side walls are actuated. Also, a non-selected ink channel, which belongs to a second group of channels having a second predetermined depth, remains unpressurized as the selected channel is actuated. Moreover, the two groups of channels are interleaved. The channels of the first group are actuated at a later time that the channels of the second group as the printhead traverses a receiver medium. This feature of the invention reduces mechanical and hydraulic coupling between channels because actuation of selected channels belonging the two groups are spaced-apart in time.

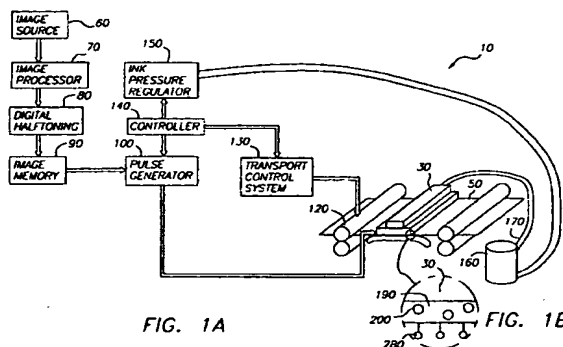


FIG. 1A

FIG. 1B

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## Description

### BACKGROUND OF THE INVENTION

[0001] The present invention generally relates to printer apparatus and methods and more particularly relates to a printer apparatus adapted to reduce cross-talk between ink channels therein, and method thereof.

[0002] An ink jet printer produces images on a receiver medium by ejecting ink droplets onto the receiver medium in an image-wise fashion. The advantages of non-impact, low-noise, low energy use, and low cost operation in addition to the capability of the printer to print on plain paper are largely responsible for the wide acceptance of ink jet printers in the marketplace.

[0003] However, one problem associated with piezoelectric ink jet printers is placement errors of the ink droplets on the receiver medium. Such errors are due, for example, to mechanical and/or hydraulic coupling (i.e., "cross-talk") between side-by-side ink channels comprising an ink jet printer printhead. That is, each ink channel, which is defined by a pair of parallel side walls made of the piezoelectric material, may share a common side wall with an adjoining channel. When an ink channel is selected for ink ejection therefrom, an electrical pulse is supplied to the side walls defining the ink channel in order to cause movement of the side walls. A pressure surge occurs in the ink channel as the side walls move, which pressure surge causes an ink droplet to eject from the ink channel. However, movement of the side walls associated with the selected ink channel in order to cause a pressure surge therein may inadvertently cause a pressure surge in an adjoining non-selected ink channel. Therefore, the pressure surge produced in the adjoining non-selected channel may inadvertently eject an ink droplet from the non-selected channel. This is so because each channel shares a common side wall with an adjoining channel. Moreover, pressure change in a channel selected for actuation may affect pressure in a remote non-adjointing channel due to a so-called "domino effect". That is, if a first channel is selected for actuation, a second channel adjoining the first channel but not selected for actuation will see change in pressure because the first and second channels share common side walls. Accordingly, a third channel not selected for actuation but adjoining the second channel will see some change in pressure because the second and third channels share common side walls. This phenomenon, referred to herein as the "domino effect" occurs for the fourth channel, the fifth channel, and so on. Eventually, this propagating pressure surge, although diminishing in intensity, may reach another actuated channel which is being intentionally actuated simultaneously with the first channel to achieve the desired droplet image pattern. However, this second actuated channel will not only experience the expected pressure surge caused by its actuation, but may also experience an unexpected pressure surge component caused by the "domino ef-

fect", which is undesirable. Such mechanical coupling (i.e., cross-talk) between the channels interferes with precise ejection of ink droplets, which in turn reduces accuracy of ink droplet placement on the receiver medium.

[0004] In addition, when ink in a selected ink channel is pressurized, the pressure surge therein may be hydraulically communicated to ink in another channel because each ink channel is in fluid communication with a common manifold holding a supply of the ink. This latter phenomenon results in hydraulic cross-talk, which in turn may lead to inadvertent ejection of an ink droplet. In other words, hydraulic cross-talk causing inadvertent ejection of an ink droplet from the non-selected channel will also produce ink droplet placement errors on the receiver medium. These ink droplet placement errors in turn produce image artifacts such as banding, reduced sharpness, extraneous ink spots, ink coalescence and color bleeding.

[0005] Techniques to reduce cross-talk are known. An ink jet printhead having low mechanical over-coupling from one channel to another is disclosed in U.S. Patent 4,842,493 titled "Piezoelectric Pump" issued June 27, 1989 in the name of Kenth Nilsson. This patent discloses a piezoceramic wafer into which grooves have been sawed from the upperside and underside of the wafer. The grooves on the upperside and underside of the wafer lay offset relative to one another and partially overlap. The grooves on the upperside of the wafer eject ink droplets while the grooves on the underside of the wafer contain only air. In this manner, deformation of the walls of one ink groove is hardly at all transmitted to another ink groove because adjacent ink grooves are effectively separated by an intervening air-filled groove.

[0006] Although the Nilsson device provides for low "cross-talk", the Nilsson device does not appear to provide means for reducing hydraulic cross-talk and also does not appear to provide means to further reduce mechanical cross-talk to a level less than that achieved only with the intervening air-filled grooves.

[0007] Therefore, an object of the present invention is to provide a printer apparatus adapted to reduce hydraulic and mechanical cross-talk between ink channels therein, and method thereof.

### SUMMARY OF THE INVENTION

[0008] The invention resides in a printer apparatus adapted to reduce cross-talk between a plurality of ink channels, characterized by a substrate including a plurality of spaced-apart pairs of selectively actuatable side walls defining respective ones of the channels therebetween for receiving associated ones of a plurality of ink bodies, said pairs of side walls being off-set one from another for reducing cross-talk between the ink bodies; and a cover plate connected to said substrate and having a plurality of orifices therethrough off-set one from another and in registration with respective ones of the

channels, whereby selected ones of the channels pressurize as selected off-set pairs of side walls actuate and whereby non-selected ones of the ink channels are pressure-free as the selected ones of the ink channels pressurize to reduce cross-talk between the ink channels.

[0009] According to one aspect of the invention, the apparatus includes a substrate having a plurality of spaced-apart pairs of actuatable side walls. Each pair of side walls can be selected for actuation independently of other pairs of side walls. Also, each pair of side walls defines an ink channel therebetween. Neighboring ink channels may have different channel depths. Each channel receives an associated one of a plurality of ink bodies therein and the substrate itself is formed of piezoelectric material responsive to electric stimuli. The pairs of side walls are preferably separated one from another by means of an intervening cut-out for reducing mechanical coupling between the ink channels. A cover plate is connected to the substrate and has a plurality of orifices therethrough in registration with respective ones of the channels such that the orifices are off-set one from another. The orifices are "in registration" with their respective ink channels in the sense that each orifice is aligned with a longitudinal axis of its associated ink channel. Preferably, each set of orifices is associated with a set of channels of a given depth. That is, the channels have different depths and, therefore, the orifices, which are in registration with the channels, are off-set one from another due to the different depths of the channels. A selected ink channel, which belongs to a first group channels having a first predetermined depth, is pressurized as its pairs of side walls are actuated. Also, a non-selected ink channel, which belongs to a second group of channels having a second predetermined depth, remains unpressurized as the selected channel is actuated. Moreover, the two groups of channels are interleaved. Hence, the channels of the first group are necessarily actuated at a later time than the channels of the second group as the printhead traverses a receiver medium. This feature of the invention reduces mechanical and hydraulic coupling between the ink bodies residing in neighboring channels because actuation of selected channels belonging to the two groups are spaced-apart in time.

[0010] The invention further comprises a plurality of electrodes connected to respective pairs of the side walls for actuating the side walls, so that the side walls move when actuated. A pulse generator is coupled to the actuators for supplying an electrical pulse to the actuators, so that the actuators are actuated with a predetermined pulse shape. Moreover, a controller is connected to the pulse generator for controlling the pulse generator, so that the pulse generator controllably supplies the predetermined pulse shape at predetermined times.

[0011] An object of the present invention is to provide a printer apparatus adapted to reduce hydraulic and mechanical cross-talk between ink channels therein, and

method thereof.

[0012] A feature of the present invention is the provision of a printhead having a cutout between neighboring ink channels for mechanically decoupling the ink channels.

[0013] Another feature of the present invention is the provision of a nozzle plate bonded to the printhead and having a plurality of orifices in registration (i.e., aligned) with respective ones of the channels, the orifices being off-set one from another for further mechanically decoupling the ink channels.

[0014] Yet another feature of the present invention is the provision of a nozzle plate bonded to the printhead and having a plurality of orifices in registration (i.e., aligned) with respective ones of the channels, the orifices being off-set one from another for hydraulically decoupling the ink channels.

[0015] An advantage of the present invention is that mechanical "cross-talk" between neighboring ink channels is reduced to a level less than that achieved only with intervening air-filled grooves.

[0016] Another advantage of the present invention is that hydraulic "cross-talk" between neighboring ink channels is reduced.

[0017] These and other objects, features and advantages of the present invention will become apparent to those skilled in the art upon a reading of the following detailed description when taken in conjunction with the drawings wherein there is shown and described illustrative embodiments of the invention.

## BRIEF DESCRIPTION OF THE DRAWINGS

[0018] While the specification concludes with claims particularly pointing-out and distinctly claiming the subject matter of the present invention, it is believed the invention will be better understood from the following description when taken in conjunction with the accompanying drawings wherein:

Figure 1 illustrates a printer apparatus belonging to the present invention, the printer apparatus comprising a printhead having a plurality of ink channels formed therein and an attached nozzle plate having a plurality of off-set orifices in registration with respective ones of the ink channels;  
Figure 2 is a fragmentation view in elevation of the printhead with the nozzle plate removed, this view showing ink channels of different depths, each pair of ink channels having a cutout therebetween;  
Figure 3 is a view in elevation of the printhead with the nozzle plate present;  
Figure 4 is a view taken along section line 4-4 of Figure 3;  
Figure 5 is a view in perspective of the printhead;  
Figure 6 is a fragmentation view in perspective of one of the ink channels;  
Figure 7 is a view in elevation of one-half portion of

one of the ink channels, this view showing direction of an electric field applied to the ink channel; Figure 8 is a view in elevation of one of the ink channels;

Figure 9a is a graph illustrating a first "square-wave" electrical pulse as a function of time applied to a first one of the ink channels, the first "square-wave" electrical pulse having a predetermined amplitude, width and start time;

Figure 9b is a graph illustrating a second "square-wave" electrical pulse as a function of time applied to a second one of the ink channels, the second "square-wave" electrical pulse having a predetermined amplitude, width and start time starting before the start time of the first "square-wave" electrical pulse;

Figure 10a is a graph illustrating a "triangular-wave" first electrical pulse as a function of time applied to a first one of the ink channels, the first "triangular-wave" electrical pulse having a predetermined amplitude, width and start time;

Figure 10b is a graph illustrating a second "triangular-wave" electrical pulse as a function of time applied to a second one of the ink channels, the second "triangular-wave" electrical pulse having a predetermined amplitude, width and start time starting before the start time of the first "triangular-wave" electrical pulse;

Figure 11a is a graph illustrating a "sinusoidally-varying" first electrical pulse as a function of time applied to a first one of the ink channels, the first "sinusoidally-varying" electrical pulse having a predetermined amplitude, width and start time, the first "sinusoidally-varying" electrical pulse also having a positive polarity portion and a negative polarity portion;

Figure 11b is a graph illustrating a second "sinusoidally-varying" electrical pulse as a function of time applied to a second one of the ink channels, the second "sinusoidally-varying" electrical pulse having a predetermined amplitude, width and start time starting before the start time of the first "sinusoidally-varying" electrical pulse, the second "sinusoidally-varying" electrical pulse also having a positive polarity portion and a negative polarity portion;

Figure 12 is a view in elevation of side walls of an ink channel inwardly moving as the positive portion of the sinusoidally-varying electrical pulse is applied thereto;

Figure 13 is a view in elevation of side walls of an ink channel outwardly moving as the negative portion of the sinusoidally-varying electrical pulse is applied thereto;

Figure 14 is a view in elevation of another embodiment of the present invention showing the printhead with the nozzle plate removed;

Figure 15 is a view in elevation of the printhead shown in Figure 14 with the nozzle plate present;

Figure 16 is a view in elevation of yet another embodiment of the present invention showing a print-head with the nozzle plate removed, this view also showing the cutouts present but with channels having the same depths; and

Figure 17 is a view in elevation of still another embodiment of the present invention showing a print-head with the nozzle plate present, this view showing channels having different depths but without the cutouts.

## DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION

[0019] The present description will be directed in particular to elements forming part of, or cooperating more directly with, apparatus in accordance with the present invention. It is to be understood that elements not specifically shown or described may take various forms well known to those skilled in the art.

[0020] Therefore, referring to Figs. 1, 2, 3, 4 and 5, there is shown a printer apparatus, generally referred to as 10, adapted to reduce "cross-talk" (i.e., mechanical and/or hydraulic coupling) between a plurality of spaced-apart elongate ink channels, such as first ink channel 20a and second ink channel 20b, each channel 20a/20b being adapted to receive an ink body 22 therein. First ink channel 20a and second ink channel 20b are formed in a printhead 30 for on-demand ejection of an ink droplet 40 therefrom that travels toward a receiver 50, which may be paper or transparency. Each of the channels 20a/20b has a channel outlet 25 at an end 27 thereof and an open side 28. Moreover, channels 20a/20b may have different depths "A" and "B", as measured from the top to the bottom thereof, for reasons disclosed hereinbelow. For reasons described in detail hereinbelow, channels 20a/20b are interleaved and, therefore, no two channels having the same depth (whether "A" or "B") neighbor each other. Channels 20a having depth "A" and channels 20b having depth "B" together define a first group of channels denoted herein as group "AB", for reasons described hereinbelow. Moreover, the grouping "AB" may be arranged in a repeating series "AB, AB", as shown.

[0021] As shown in Figs. 1, 2, 3, 4 and 5, printer apparatus 10 comprises an image source 60, which may be raster image data from a scanner or computer, or outline image data in the form of a PDL (Page Description Language) or other form of digital image representation. This image data is transmitted to an image processor 70 connected to image source 60. Image processor 70 converts the image data to a pixel-mapped page image. Image processor 70 may be a raster image processor in the case of PDL image data to be converted, or a pixel image processor in the case of raster image data to be converted. In any case, image processor 70 transmits continuous tone data to a digital halftoning unit 80 connected to image processor 70. Halftoning unit 80 half-

tones the continuous tone data produced by image processor 70 and produces halftoned bitmap image data that is stored in an image memory 90, which may be a full-page memory or a band memory depending on the configuration of printer apparatus 10. A pulse generator 100 connected to image memory 90 reads data from image memory 90 and applies time and amplitude varying electrical pulses to an electrical actuator 110 (i.e., an electrode), for reasons described more fully hereinbelow.

**[0022]** As best seen in Figs. 1 and 2, printhead 30 is moved in a direction 115 relative to receiver 50 by means of a transport mechanism 120, which is electronically controlled by a transport control system 130. Transport control system 130 in turn is controlled by a suitable controller 140. It may be appreciated that different mechanical configurations for transport control system 130 are possible. For example, in the case of page width printheads, it is convenient to move receiver 50 past a stationary printhead 30. On the other hand, in the case of scanning-type print systems, it is more convenient to move printhead 30 along one axis (i.e., a "sub-scanning" direction) and receiver 50 along an orthogonal axis (i.e., a "main scanning" direction), in relative raster motion.

**[0023]** Still referring to Figs. 1 and 2, controller 140 may be connected to an ink pressure regulator 150 for controlling regulator 150. Regulator 150 is capable of regulating pressure in an ink reservoir 160. Ink reservoir 160 is connected, such as by means of a conduit 170, to printhead 30 for supplying liquid ink to printhead 30. In this regard, ink is preferably distributed under controlled negative pressure to a back surface of printhead 30 by an ink channel device (not shown) belonging to printhead 30 and from there into channels 20a/20b.

**[0024]** Referring now to Figs. 3, 5 and 6, printhead 30 comprises a generally cuboid-shaped preferably one-piece substrate 180 formed of a piezoelectric material, such as lead zirconium titanate (PZT), which is responsive to electrical stimuli. In the preferred embodiment of the invention, piezoelectric substrate 180 is poled generally in the direction of an arrow 185. Of course, the poling direction may be oriented in other directions, if desired, such as in a direction perpendicular to the poling direction shown by arrow 185. Cut into substrate 180 are the previously mentioned plurality of elongate ink channels 20a/20b. Ink channels 20a/20b are covered at outlets 25 by a nozzle plate 190 having a plurality of orifices 200 preferably aligned in registration with respective ones of channels 20a/20b, so that ink droplets 20 are ejected from channel outlets 25 and through orifices 200. Orifices 200 are "in registration" with their respective ink channels 20a/20b in the sense that each orifice 200 is aligned with a longitudinal axis of its associated ink channel 20a/20b. Preferably, each set of orifices is associated with a set of channels of a given depth. That is, channels 20a have a different channel depth compared to channels 20b and, therefore, orifices 200,

which are in registration with the channels 20a/20b, are off-set one from another due to the different channel depths of channels 20a/20b. As previously mentioned, channels 20a and 20b may have the different channel depths "A" and "B", respectively. Moreover, the orifices 200 associated with channels 20a having depth "A" are horizontally aligned along a first axis 205. Similarly, the orifices 200 associated with channels 20b having depth "B" are horizontally aligned along a second axis 207.

The vertical locations of orifices 200 relative the bottom of their corresponding channels 20a and 20b can be chosen to optimize the properties of the ink droplets ejected from the channels 20a and 20b so that, if desired, essentially identical ink droplets 40 can be ejected from channels 20a and 20b. Ink properties include ink droplet volume, speed, and the like. Off-set orifices 200 associated with the shallower channels 20a have additional piezoelectric material below the shallower channels 20a to provide somewhat more mechanical energy to these channels 20a, in order to compensate for the offset location of their orifices 200. Thus, neighboring orifices 200 are off-set one from another and located at optimized positions to their corresponding channels 20a/20b which have different depths "A" and "B". When printhead 30 travels in direction of arrow 115, the off-set positions of the neighboring orifices 200 permit ink droplets 40 to be actuated and ejected at different times in neighboring channels 20a and 20b so that mechanical and/or hydraulic cross-talk between channels 20a/20b are reduced. It is understood that other locations of orifices 200 can be arranged for channels 20a and 20b to optimize ink droplet properties.

**[0025]** Referring to Figs. 4, 5 and 6, nozzle plate 190 is connected to substrate 180, such as being bonded thereto by a suitable adhesive. A rear cover plate (not shown) is also provided for capping the rear of channels 20a/20b. In addition, a top cover plate 200 caps channels 20a/20b along open sides 28. During operation of apparatus 10, ink from reservoir 160 is controllably supplied to the previously mentioned ink channel device (not shown) by means of conduit 170 and from there into each channel 20a/20b.

**[0026]** Referring to Figs. 2, 3, 6 and 7, the specific structure of substrate 180 will now be described. Substrate 180 comprises a plurality of spaced-apart pairs of actuatable side walls 220/230. That is, substrate 180 includes a plurality of first side walls 220 and a plurality of opposing second side walls 230, each pair of side walls 20a/20b defining respective channels 20a/20b therebetween. Neighboring channels 20a/20b have the previously mentioned different depths "A" and "B", respectively. Each pair of side walls 220/230 can be selected for actuation independently of other pairs of side walls 220/230. Each channel 20a/20b is adapted to receive ink body 200 therein. First side wall 220 includes an outside surface 225 and second side wall 230 includes an outside surface 235. Substrate 180 also includes a base portion 240 interconnecting first side wall 220 and sec-

ond side wall 230, so as to form a generally U-shaped piezoelectric structure. Upper-most surfaces (as shown) of first wall 220 and second wall 230 together define a top surface 250 of substrate 180 and a lower-most surface (as shown) of base portion 240 defines a bottom surface 260 of substrate 180. An addressable electrode actuator layer 270 extends from approximately half-way up outside surface 225, across bottom surface 260, to approximately half-way up outside surface 235. However, it may be understood that electrode actuator layer 270 may extend any suitable distance up surfaces 225 and 235, such as, for example all the way up surfaces 225 and 235. Moreover, actuator layer 270 is connected to the previously mentioned pulse generator 100. Pulse generator 100 supplies electrical drive signals to actuator layer 270 by means of electrical conducting terminal 280.

[0027] Referring yet again to Figs. 2, 3, 6 and 7, a common electrode layer 290 coats each channel 20a/20b and also extends therefrom along top surface 250. Common electrode layer 290 is preferably connected to a ground electrical potential, as at a point 300. In this configuration of actuator layer 270, an electrical field "E" is established between electrode actuator layer 270 and common electrode layer 290 in a predetermined orientation with respect to poling direction 185. Alternatively, common electrode layer 290 may be connected to pulse generator 100 for receiving electrical drive signals therefrom. However, it is preferable to maintain common electrode layer 290 at ground potential because common electrode layer 290 is in contact with liquid ink in channel 20a/20b. That is, it is preferable to maintain common electrode layer 290 at ground potential in order to minimize electrolysis effects on common electrode layer 290 when in contact with liquid ink in channels 20a/20b, which electrolysis may otherwise act to degrade performance of common electrode layer 290 as well as the ink.

[0028] As best seen in Fig. 2, each ink channel 20a/20b is separated from its neighbor by a cutout 305, which may be filled with air or a resilient shock-absorbing elastomer (not shown), for reducing mechanical "cross-talk" between channels 20a/20b. This is so because, when either side wall 220 or 230 laterally moves, it will move into cutout 305 rather than move into channel 20a/20b. Also, presence of the previously mentioned ink channel device (not shown) provides a means for reducing hydraulic cross-talk between ink channels 20a/20b. This is so because, as previously mentioned, reservoir 160 supplies ink to the ink channel device. Each channel 20a/20b is in fluid communication with the ink channel device. Thus, a pressure surge in one channel may be inadvertently communicated to another ink channel due to the ink channels having common communication with the ink channel device. This hydraulic cross-talk between neighboring channels is lessened by use of the invention because channels 20a/20b are not activated simultaneously. This in turn lessens the amplitude of in-

advertent pressure surges occurring in channel 20a (or channel 20b). Hydraulic cross-talk between the channels 20a/20b is undesirable because such cross-talk would otherwise interfere with precise ejection of ink droplets 20 from channels 20a/20b. Interference with precise ejection of ink droplets 20 in turn reduces accuracy of ink droplet placement on receiver medium 30. Thus, each cutout 305 is defined between respective pairs of side walls 220/230, so that channels 20a/20b are mechanically decoupled by presence of cutouts 305. Also, both mechanical and hydraulic cross-talk is lessened because channels 20a and 20b are not activated simultaneously.

[0029] Referring now to Figs. 8, 9a, 9b, 10a and 10b, there is shown substrate 180 undergoing deformation in order to pressurize ink bodies 200 residing in either channels 20a or channels 20b so as to eject ink droplet 40 along an ejection path preferably normal to orifice 200. To achieve pressurization of ink body 200, pulse generator 100 supplies an electrical pulse 310 to actuator layer 270. As previously mentioned, side walls 220/230 of channels 20a are actuated to move at a predetermined time after side walls 220/230 of channel 20b, as printhead 30 travels in direction of arrow 115. In this manner, mechanical cross-talk between channels 20a/20b is further reduced to a level less than the amount of reduction in cross-talk due to presence of cut-outs 305 alone. More specifically, pulse generator 100 in combination with controller 140 controls timing of movement of the pairs of side walls 220/230 associated with each channel 20a/20b. More specifically, pulse 310 is applied individually to channels 20a and 20b at different starting times. In this regard, pulse 310 has a predetermined amplitude  $V_A$ , a predetermined pulse width  $\Delta t_A$  and a predetermined pulse start time  $t_{sA}$  when pulse 310 is applied to actuator layer 270 associated with channel 20a. Similarly, pulse 310 has a predetermined amplitude  $V_B$ , a predetermined pulse width  $\Delta t_B$  and a predetermined pulse start time  $t_{sB}$  when pulse 310 is applied to actuator layer 270 associated with channel 20b. However, start time  $t_{sA}$  occurs after  $t_{sB}$ . Also, it may be appreciated that amplitudes  $V_A$  and  $V_B$  may differ in order to compensate for different electro-mechanical effects occasioned by grouping channels 20a/20b into group AB. In this regard, the presence of channels 20a/20b having different depths "A" and "B" may give rise to different electro-mechanical effects (e.g., different ink droplet volume, different ink droplet ejection speed, and other effects). The invention is capable of compensating for these different electro-mechanical effects, which may be caused by the different channel depths, by allowing for different voltage amplitudes  $V_A$  and  $V_B$ , if desired.

[0030] Referring now to Figs. 8, 9a, 9b, 10a and 10b, piezoelectric substrate 180, which is responsive to the electrical stimuli supplied to actuator layer 270 by pulse 310, deforms such that first side wall 220 and second side wall 230 inwardly move to positions 220' and 230',

as shown by phantom lines. Moreover, base portion 240 will likewise inwardly move to position 240', as shown by phantom lines. It should be appreciated that first side wall 220, second side wall 230 and base portion 240 move due to the inherent nature of piezoelectric materials, such as the PZT piezoelectric material forming substrate 180. In this regard, it is known that when an electrical signal is applied to a piezoelectric material, mechanical distortion occurs in the piezoelectric material. This mechanical distortion is dependent on the poling direction and the direction of the applied electrical field "E". Thus, according to the present invention, electric field "E" is in a direction generally parallel to poling direction 185 near base portion 240 in order to cause base portion 240 to deform and compress to position 240' in non-shear mode. In addition, electric field "E" is in a direction generally perpendicular to poling direction 185 near side walls 220/230 to cause side walls 220/230 to deform to positions 220'/230' in shear mode. That is, side walls 220/230 will deform into a generally parallelogram shape, rather than the compressed shape in which base portion 240 deforms. In this manner, substrate 180 becomes longer and thinner in a direction parallel to poling direction 185. Once electrical pulse 310 ceases, side walls 220/230 and base portion 240 return to their undeformed positions to await further electrical excitation.

**[0031]** Moreover, referring to Figs. 11a, 11b, 12 and 13, it may be appreciated that an applied voltage of one polarity (i.e., either positive or negative polarity) will cause substrate 180 to bend in a first direction and an applied voltage of the opposite polarity will cause substrate 180 to deform in a second direction opposite to the first direction. For example, when a sinusoidally-varying pulse 320 having a positive polarity portion 325 and a negative polarity portion 327 is applied to actuator layer 270 associated with each channel 20a/20b, side walls 220/230 will move inwardly and outwardly depending on whether the polarity of pulse 320 is positive or negative, respectively. More specifically, during the positive polarity portion 325, first side wall 220 and second side wall 230 will move inwardly to positions 220' and 230', as shown in Fig. 12. Similarly, during the negative polarity portion 327, first side wall 220 and second side wall 230 will move outwardly to positions 220" and 230", as shown Fig. 13. Moreover, pulse 320 which is applied to channel 20a has a positive amplitude "+V<sub>A</sub>" and a negative amplitude "-V<sub>A</sub>". Also, pulse 320 which is applied to channel 20a also has a start time t<sub>sA</sub> and pulse width Δt<sub>A</sub>. Similarly, pulse 320 which is applied to channel 20b has a positive amplitude "+V<sub>B</sub>" and a negative amplitude "-V<sub>B</sub>". Also, pulse 320 which is applied to channel 20b has a start time t<sub>sB</sub> and pulse width Δt<sub>B</sub>. Start time t<sub>sA</sub> occurs after start time t<sub>sB</sub>. This configuration of the invention allows greater volume of ink to be ejected during each droplet ejection cycle. This is so because, when side walls 220/230 outwardly move to positions 220"/230", volume of first channel 20a (or second channel

20b, as the case may be) increases to accommodate greater volume of ink therein before droplet 40 is ejected, which occurs when side walls 220/230 inwardly move to positions 220'/230'. It may be understood from the teachings herein, that when ejection of less volume of ink in each droplet 40 is desired, then sinusoidal pulse 320 is not supplied to actuator layer 270; rather, the "square-wave" pulse of Figs. 9a and 9b or the "triangular-wave" pulse of Figs. 10a and 10b is supplied. In this manner, printer apparatus 10 is capable of controlling ink droplet volume depending on whether pulse 310 is applied or pulse 320 is applied. Printer apparatus 10 is also capable of controlling ink droplet volume in yet another manner. In this regard, amplitude of pulse 310 or pulse 320 can be controlled by pulse generator 100 in order to control volume of ink forming ink droplet 40.

**[0032]** Turning now to Figs. 14 and 15, an alternative embodiment of the present invention is there shown having first channel 20a, second channel 20b and a third channel 20c formed in printhead 30. Channels 20a, 20b and 20c have different depths "A", "B", and "C", respectively. Channels 20c has a depth "C" different from depths "A" and "B" and together defining a second grouping of channels denoted herein as grouping "ABC". The grouping "ABC" may be arranged in a repeating series, as shown. In this manner, channels having the same depth are not located adjacent each other. The "AB" and the "ABC" groups are different to the extent that distance between ink channels for the two groups are different. For example, in the case of the "AB" group, channels 20a/20b may be simultaneously activated without mechanical cross-talk. This is so because the distance between channels 20a (or channels 20b) is two "channel widths". In the case of the "ABC" group, the channels 20a/20b/20c may be simultaneously activated without mechanical cross-talk. This is so because the distance between channels 20a (or channels 20b, or channels 20c) is three "channel widths". Mechanical cross-talk is further reduced by this latter "ABC" configuration compared to the "AB" configuration because ink channels are further apart in the "ABC" grouping compared to the "AB" grouping. It may be appreciated that more than two groupings of channels may be provided. In addition, it may be appreciated that groupings of channels may be arranged in any suitable pattern, such as the periodic pattern (e.g., ABC, ABC) illustrated herein or a non-periodic pattern (e.g., ABCA, ABCD), if desired.

**[0033]** Referring to Fig. 16, another embodiment of the present invention is there shown for reducing mechanical and hydraulic cross-talk between neighboring channels 20a/20b. In this alternative embodiment of the invention, orifices 200 are again off-set; however, channels 20a/20b have the same depth. Mechanical and hydraulic cross-talk is reduced also in this embodiment of the invention because neighboring channels are not actuated simultaneously. This alternative embodiment of the invention reduces manufacturing costs because no

provision need be made for machining channels of different depths.

[0034] Referring to Fig. 17, yet another embodiment of the present invention is there shown for reducing mechanical and hydraulic cross-talk between neighboring channels. In this alternative embodiment of the invention, channels 20a/20b have different depths and orifices 200 are again off-set. However, cutouts 305 are absent. Mechanical and hydraulic cross-talk is reduced also in this embodiment of the invention because neighboring channels are not actuated simultaneously. This alternative embodiment of the invention reduces manufacturing costs because no provision need be made for machining cutouts 305.

[0035] It is understood from the description hereinabove that an advantage of the present invention is that mechanical "cross-talk" between neighboring ink channels is reduced. This is so because presence of cutout 305 mechanically decouples one channel from its neighboring channel.

[0036] It is also understood from the description hereinabove that another advantage of the present invention is that mechanical and/or hydraulic "cross-talk" between neighboring ink channels is reduced because orifices 200 are off-set one from another. Orifices 200 are off-set so that neighboring channels are not actuated simultaneously. Such non-simultaneous actuation of neighboring ink channels results in reduced mechanical and hydraulic cross-talk between the channels.

[0037] The invention has been described in detail with particular reference to certain preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention. For example, although the invention is described herein as suitable for ejecting ink droplets, the invention is equally suitable for ejecting droplets formed of other substances, such as clear liquid polymers (i.e., clear liquid plastics) used as a protective layer on photographs.

[0038] Therefore, what is provided is a printer apparatus adapted to reduce cross-talk between ink channels therein, and method thereof.

#### PARTS LIST:

##### [0039]

A	depth of first ink channel 20a
B	depth of second ink channel 20b
C	depth of third ink channel 20c
$t_{sA}$	start time for voltage applied to channel 20a
$t_{sB}$	start time for voltage applied to channel 20b
$\Delta t_{sA}$	voltage pulse width applied to channel 20a
$\Delta t_{sB}$	voltage pulse width applied to channel 20b
$V_A$	voltage pulse amplitude applied to channel 20a
$V_B$	voltage pulse amplitude applied to channel 20b
10	printer apparatus
20a	first ink channel

20b	second ink channel
20c	third ink channel
22	ink body
25	channel outlet
5 27	end of ink channel
28	open side of ink channel
30	printhead
40	ink droplet
50	receiver
10 60	image source
70	image processor
80	halftoning unit
90	memory
100	pulse generator
15 110	actuator
115	direction of movement of printhead
120	transport mechanism
130	transport control system
140	controller
20 150	ink pressure regulator
160	ink reservoir
170	conduit
180	substrate
185	arrow
25 190	nozzle plate
200	orifice
205	first axis of alignment for orifices
207	second axis of alignment for orifices
210	top cover plate
30 220	first side wall
220'	position of first side wall after inwardly moving
220"	position of first side wall after outwardly moving
225	outside surface of first side wall
230	second side wall
35 230'	position of second side wall after inwardly moving
230"	position of second side wall after outwardly moving
235	outside surface of second side wall
40 240	base portion
240'	position of base portion after inwardly moving
250	top surface
260	bottom surface
270	electrode actuator layer
45 280	electrical terminal
290	common electrode layer
300	ground
305	cut-out
310	electrical pulse
50 320	sinusoidally-varying pulse
325	positive portion of sinusoidally-varying pulse
327	negative portion of sinusoidally-varying pulse

##### 55 Claims

1. A printer apparatus adapted to reduce cross-talk between a plurality of ink channels (20a, 20b, 20c),



characterized by:

- (a) a substrate (180) including a plurality of spaced-apart pairs of selectively actuatable side walls (220, 230) defining respective ones of the channels therebetween for receiving associated ones of a plurality of ink bodies (22), said pairs of side walls being off-set one from another for reducing cross-talk between the ink bodies; and
  - (b) a cover plate (190) connected to said substrate and having a plurality of orifices (200) therethrough off-set one from another and in registration with respective ones of the channels, whereby selected ones of the channels pressurize as selected off-set pairs of side walls actuate and whereby non-selected ones of the ink channels are pressure-free as the selected ones of the ink channels pressurize, so that cross-talk between the channels is reduced.
2. The apparatus of claim 1, further characterized by a plurality of actuators (270, 290) connected to respective pairs of said side walls for actuating said side walls.
3. The apparatus of claim 2, wherein said actuators are electrically actuatable.
4. The apparatus of claim 3, further characterized by a pulse generator (100) coupled to said actuators for supplying an electrical pulse to said actuators, so that said actuators are selectively electrically actuated.
5. The apparatus of claim 4, further characterized by a controller (140) connected to said pulse generator for controlling said pulse generator, so that said pulse generator controllably supplies the electrical pulse.
6. The apparatus of claim 1, wherein neighboring ones of said pairs of side walls are separated by a cut-out (305) for further reducing cross-talk between ink bodies.
7. The apparatus of claim 1, wherein the channels defined by said side walls have different depths (A, B, C).
8. A printhead, characterized by:
  - (a) two pairs of spaced-apart piezoelectric side walls (220, 230) defining two channels, respectively, said pairs of side walls being off-set one from another for reducing cross-talk between the channels; and
  - (b) a cover plate (190) connected to said side walls and spanning the channels, said cover plate having a plurality of orifices (200) off-set one from another and in registration with respective ones of the channels.
9. The printhead of claim 8, further characterized by a plurality of actuators (270, 290) connected to respective pairs of said side walls for actuating said side walls.
10. The printhead of claim 9, further characterized by a pulse generator (100) coupled to said actuators for supplying an electrical pulse to said actuators, so that said actuators are selectively electrically actuated.
11. The printhead of claim 9, wherein neighboring ones of said pairs of side walls are separated by a cut-out (305) for further reducing cross-talk between ink channels.
12. The printhead of claim 9, wherein the channels defined by said pairs of side walls have different depths (A, B, C).
13. In a printer, a method of reducing cross-talk between a plurality of ink channels (20a, 20b, 20c) disposed therein, characterized by the steps of:
  - (a) using a substrate (180) including a plurality of spaced-apart pairs of selectively actuatable side walls (220, 230) defining respective ones of the channels therebetween, the pairs of side walls being off-set one from another for reducing cross-talk between the channels; and
  - (b) connecting a cover plate (190) to the substrate, the substrate having a plurality of orifices (200) therethrough off-set one from another and in registration with respective ones of the channels, whereby selected ones of the channels pressurize as selected off-set pairs of side walls actuate and whereby non-selected ones of the channels are pressure-free as the selected ones of the ink channels pressurize, so that cross-talk between the ink channels is reduced.
14. The method of claim 13, further characterized by the step of connecting a plurality of actuators (270, 290) to respective pairs of the side walls for actuating the side walls.
15. The method of claim 14, wherein the step of connecting a plurality of actuators is characterized by the step of connecting a plurality of electrically actuatable actuators.
16. The method of claim 14, further characterized by the step of coupling a pulse generator (100) to the

actuators for supplying an electrical pulse to the actuators, so that the actuators are selectively electrically actuated.

17. The method of claim 16, further characterized by the step of connecting a controller (140) to the pulse generator for controlling the pulse generator, so that the pulse generator controllably supplies the electrical pulse. 5
- 10
18. The method of claim 13, wherein the step of using a substrate is characterized the step of using a substrate having neighboring ones of the pairs of side walls separated by a cut-out (305) for further reducing cross-talk between channels. 15
19. The method of claim 13, wherein the step of using a substrate is characterized the step of using a substrate wherein the channels defined by said pairs of side walls have different depths (A, B, C). 20
20. In a printhead, a method of reducing cross-talk, characterized by the steps of:
- (a) using two spaced-apart pairs of side walls (220, 230) defining two channels, respectively, the pairs of the side walls being off-set one from another for reducing mechanical coupling between the channels; and 25
- (b) connecting a cover plate (190) to the side walls, the cover plate spanning the channels, the cover plate having a plurality of orifices off-set one from another and in registration with respective ones of the channels. 30
- 35
21. The method of claim 20, further characterized by the step of connecting a plurality of actuators (270, 290) to respective pairs of the side walls for actuating the side walls. 40
22. The method of claim 21, further characterized by the step of coupling a pulse generator (100) to the actuators for supplying an electrical pulse to the actuators, so that the actuators are selectively electrically actuated. 45
23. The method of claim 20, wherein the step of using a substrate is characterized by the step of using a substrate having neighboring ones of the pairs of side walls separated by a cut-out (305) for further reducing cross-talk between ink channels. 50
24. The method of claim 20, wherein the step of using a substrate is characterized by the step of using a substrate wherein the channels defined by said pairs of side walls have different depths (A, B, C). 55

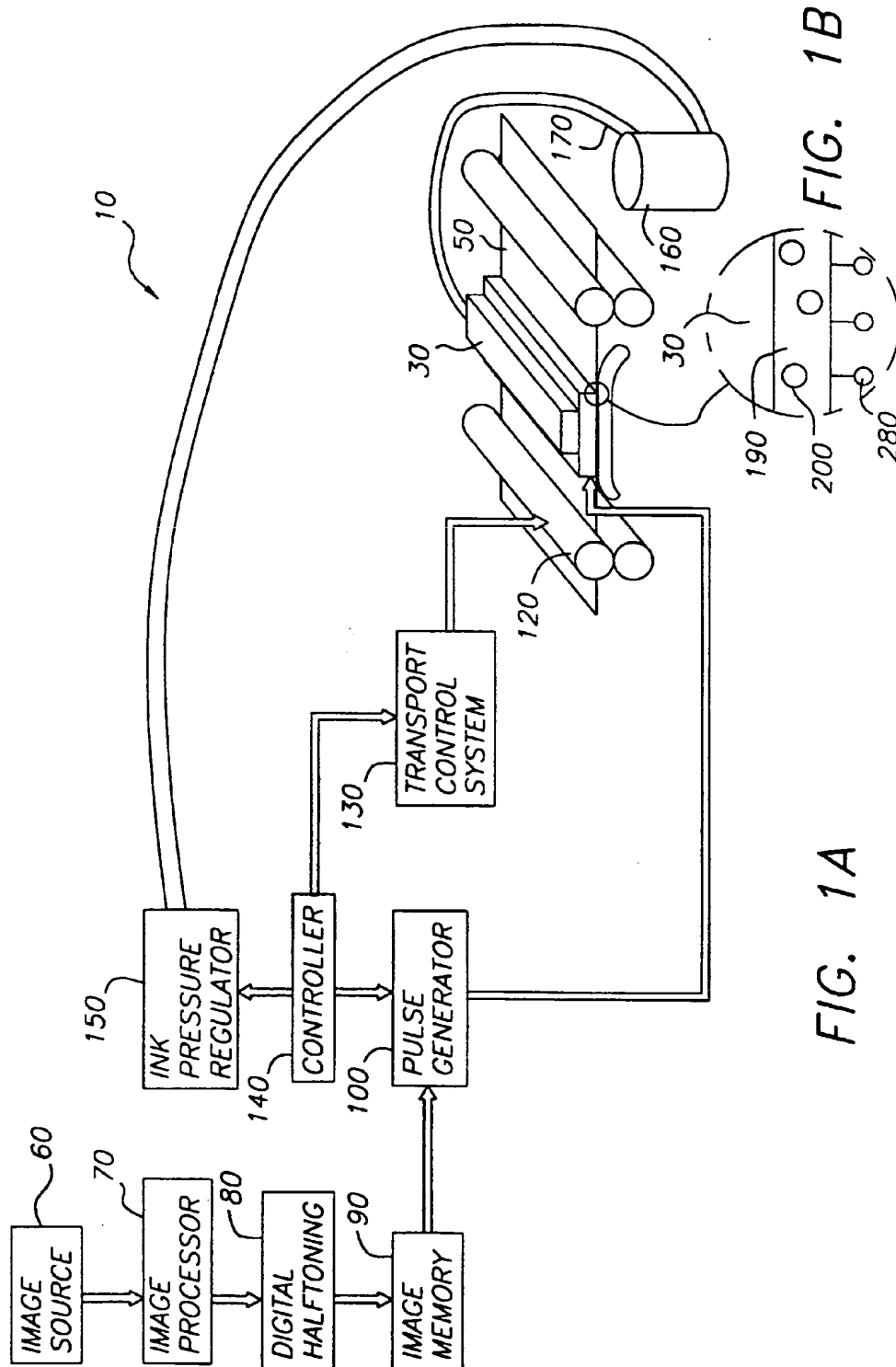


FIG. 1A

FIG. 1B

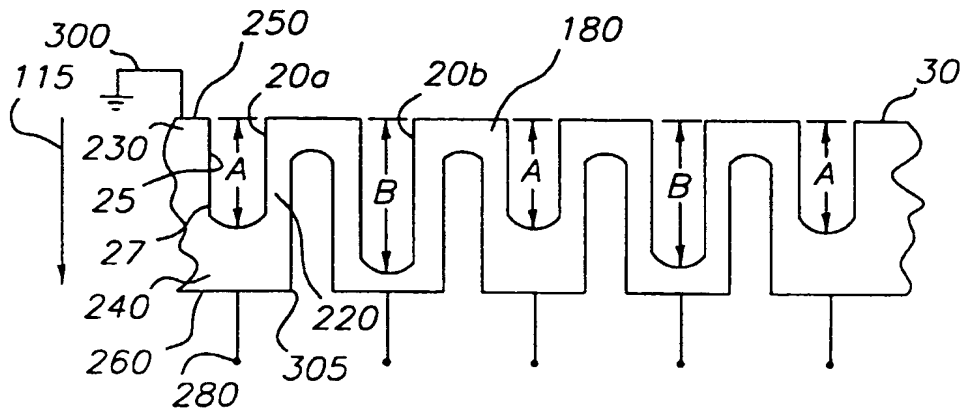


FIG. 2

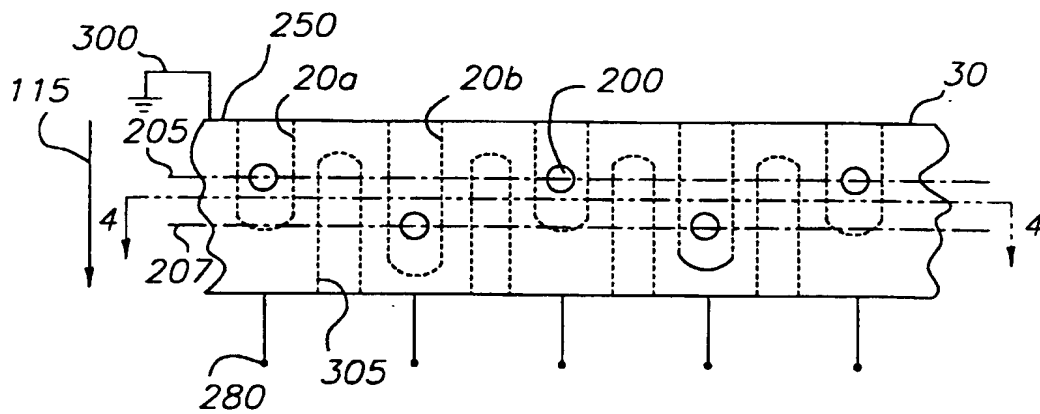


FIG. 3

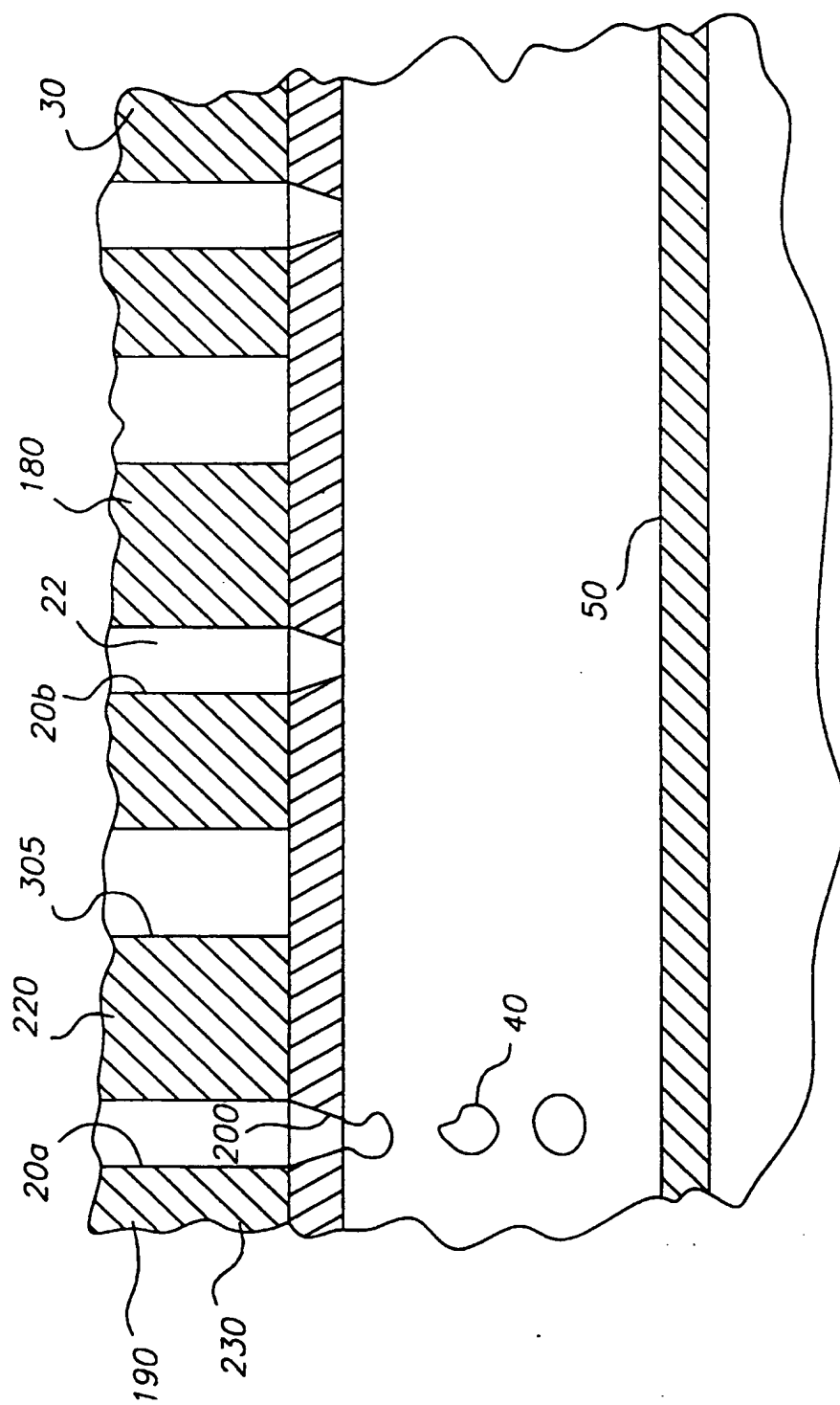


FIG. 4

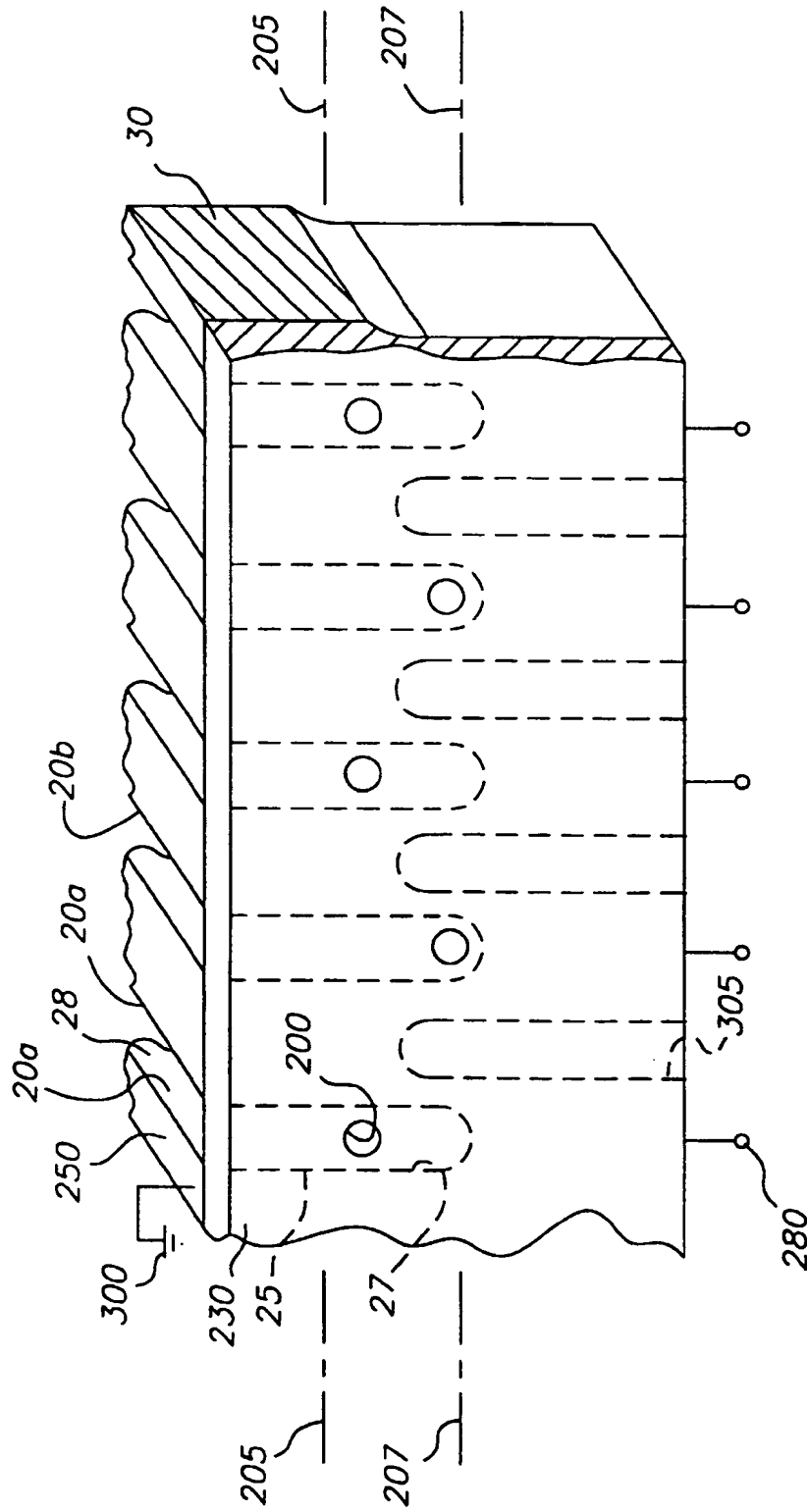


FIG. 5

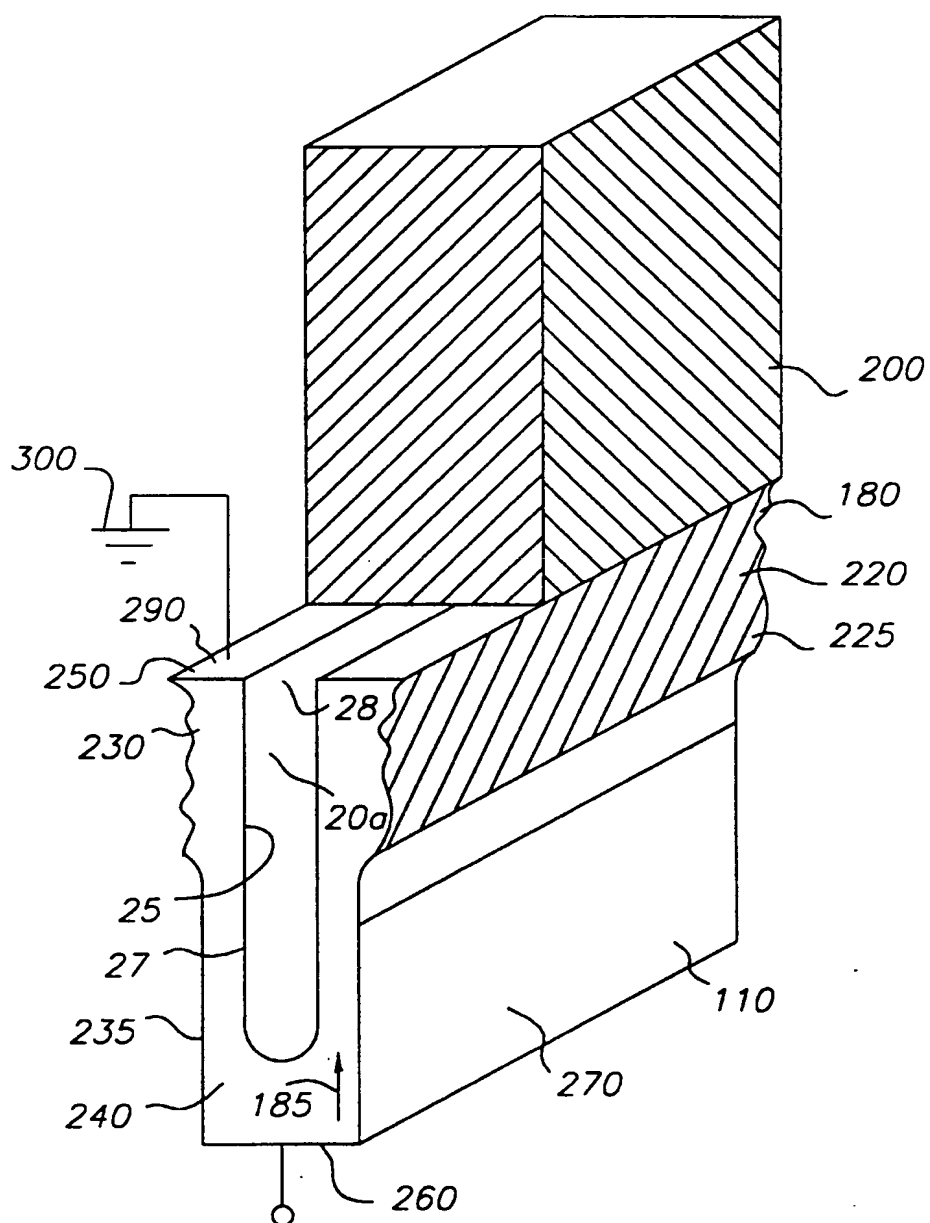


FIG. 6

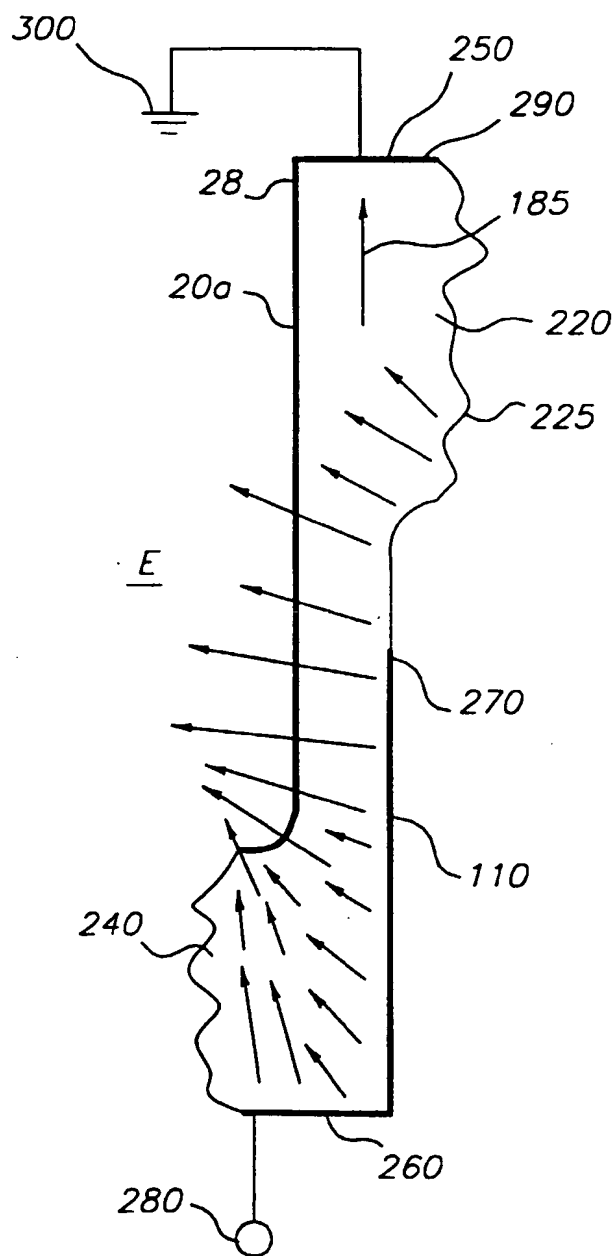


FIG. 7



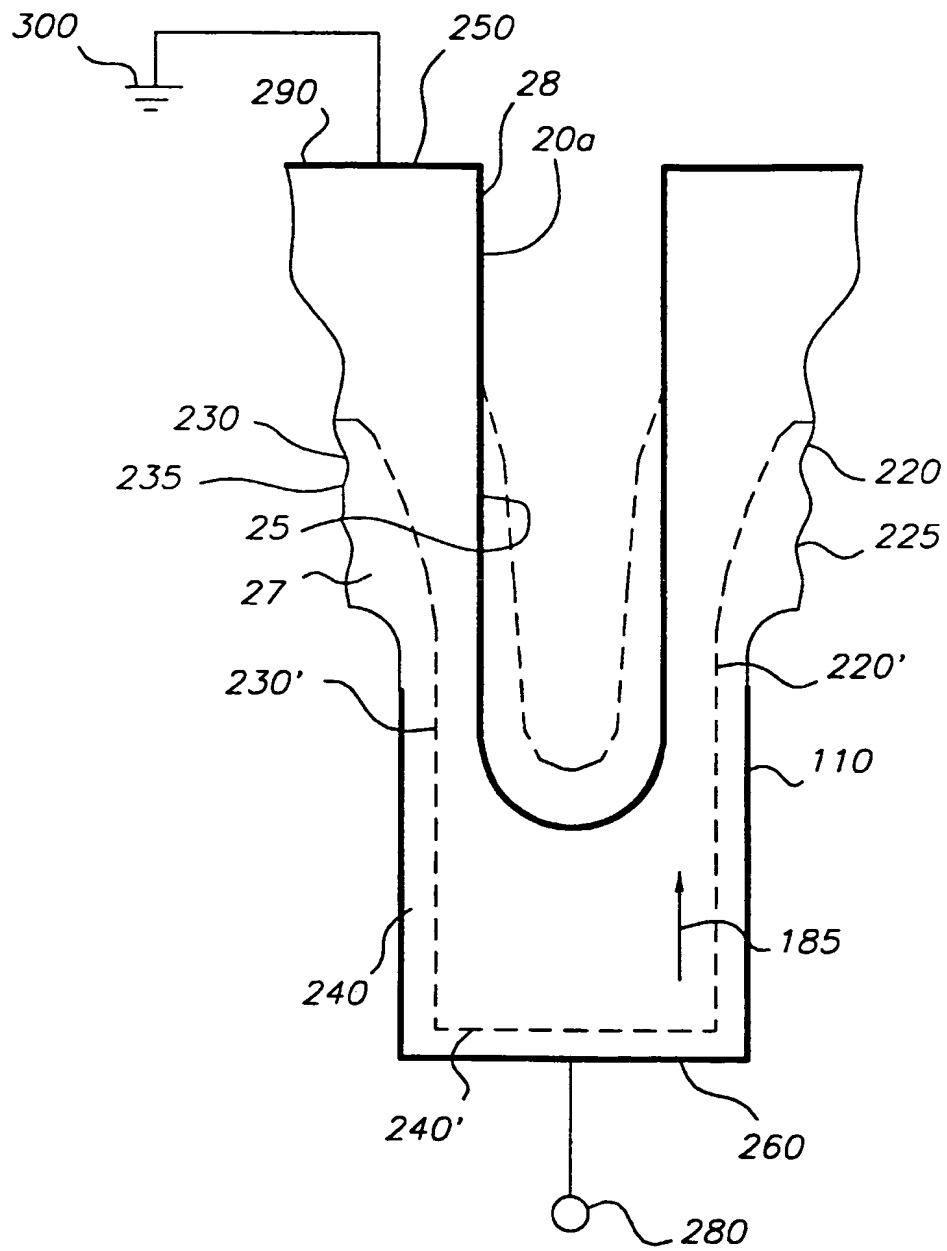


FIG. 8

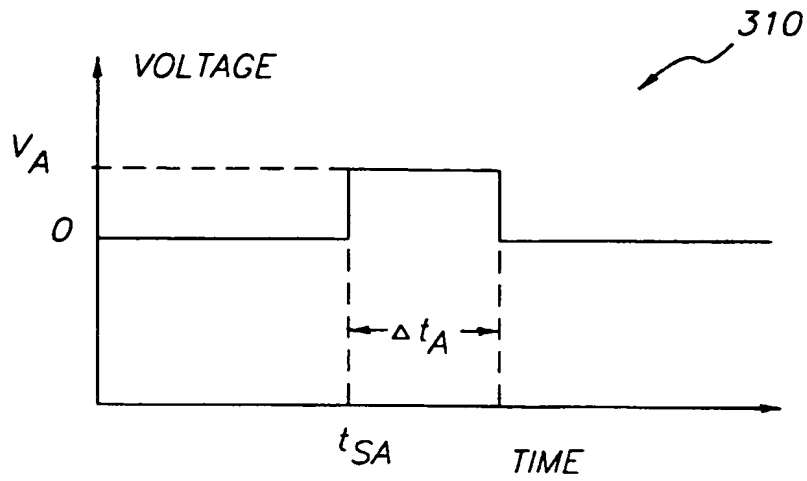


FIG. 9a

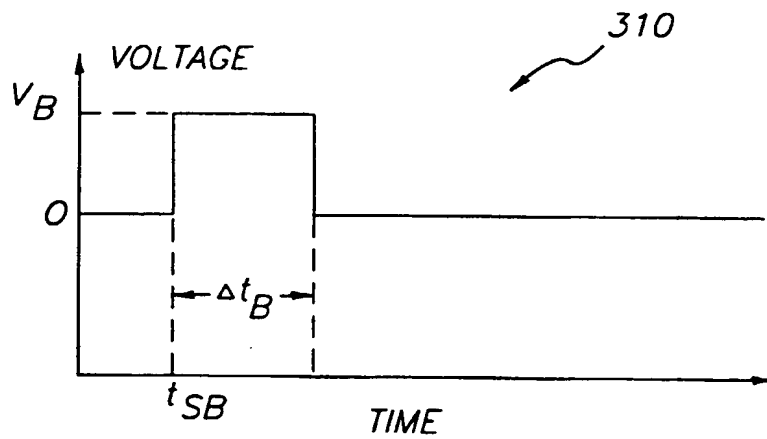


FIG. 9b

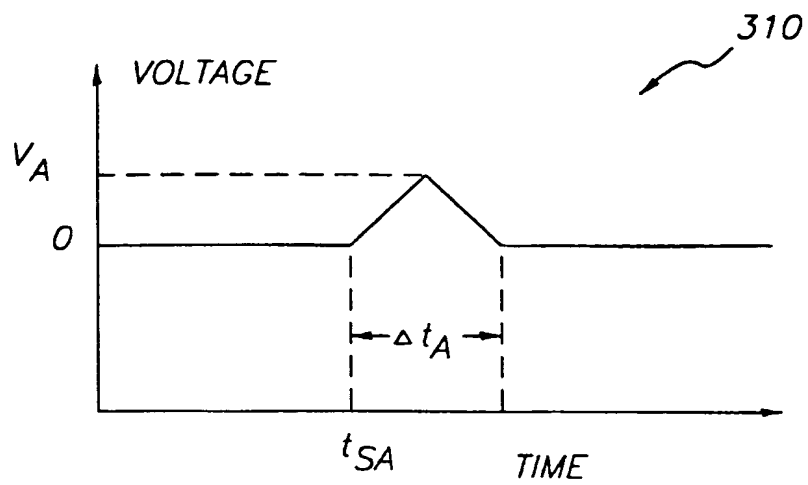


FIG. 10a

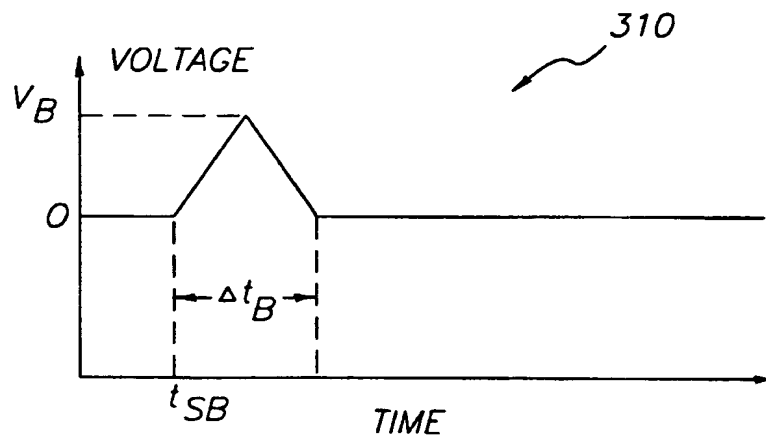


FIG. 10b

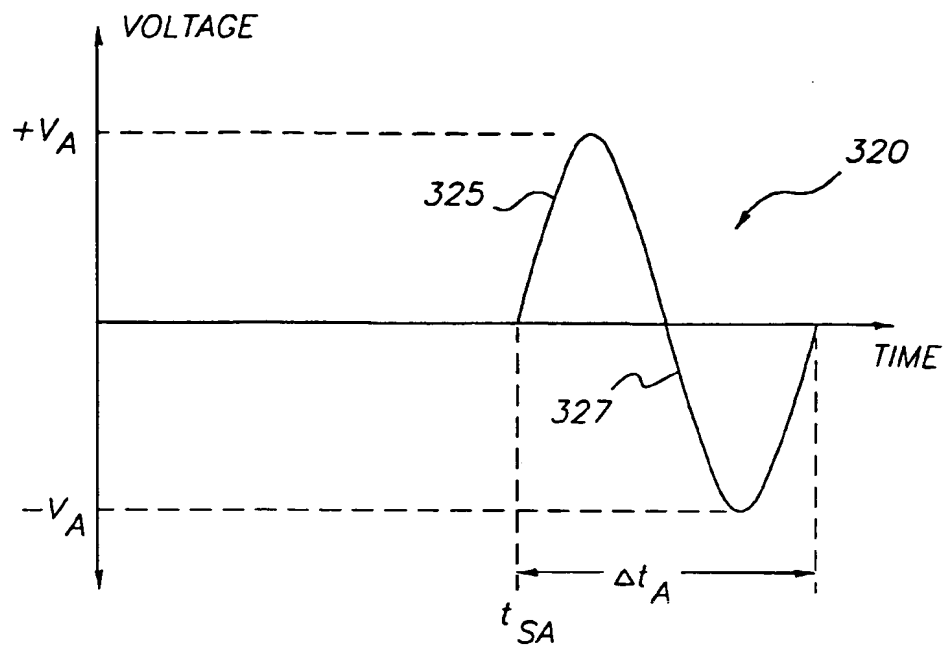


FIG. 11a

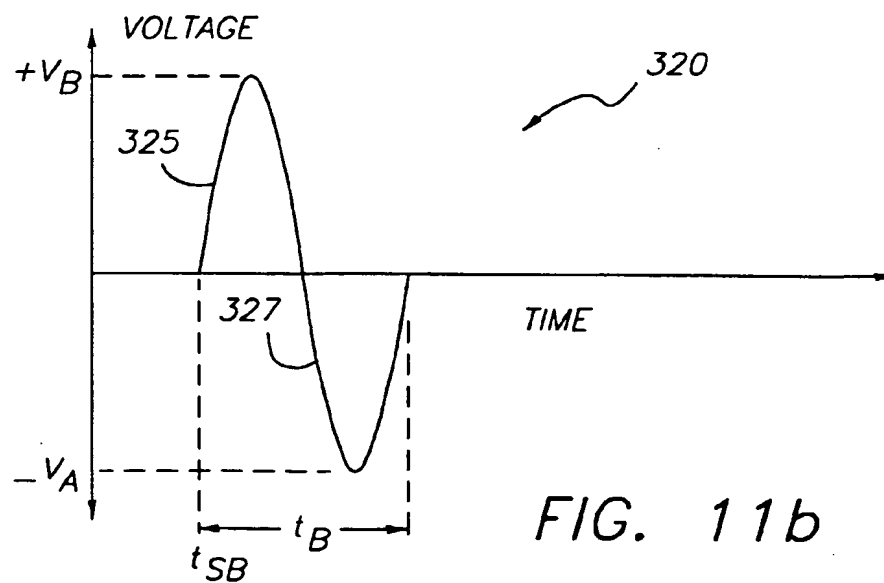


FIG. 11b

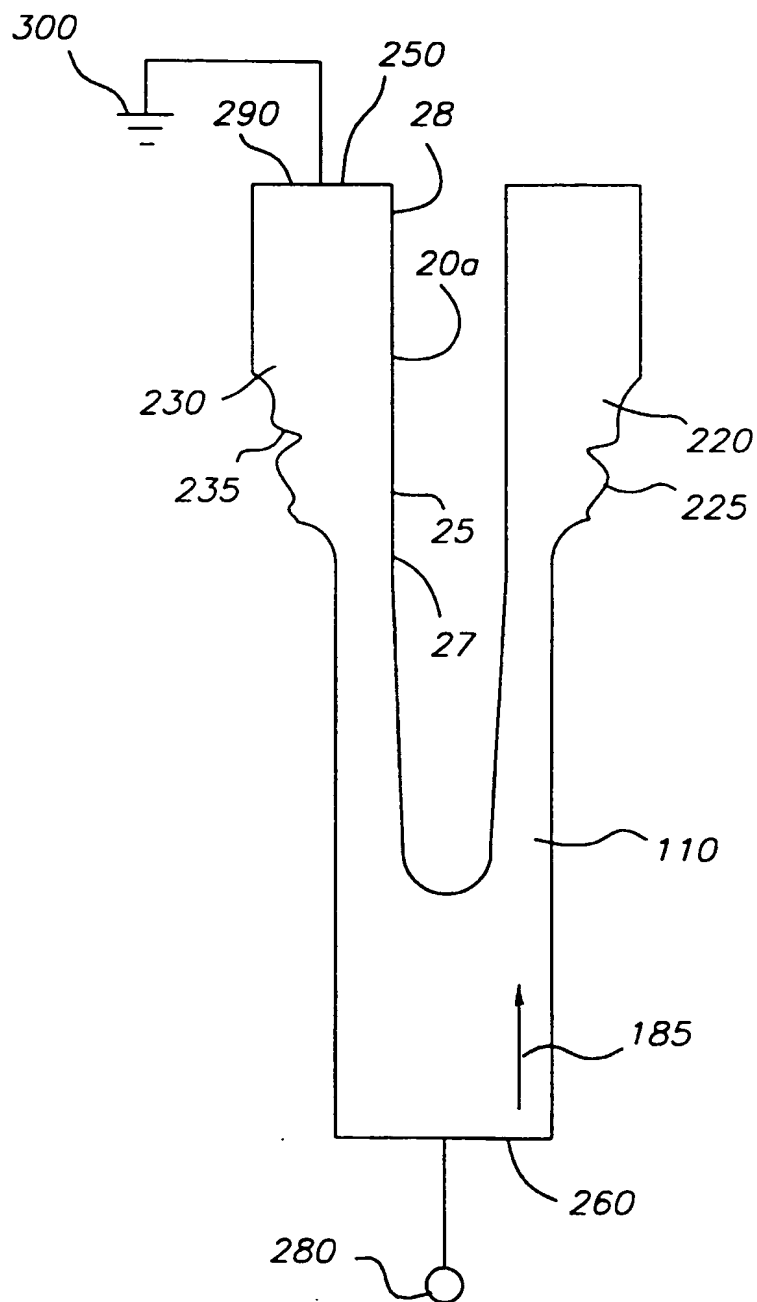


FIG. 12

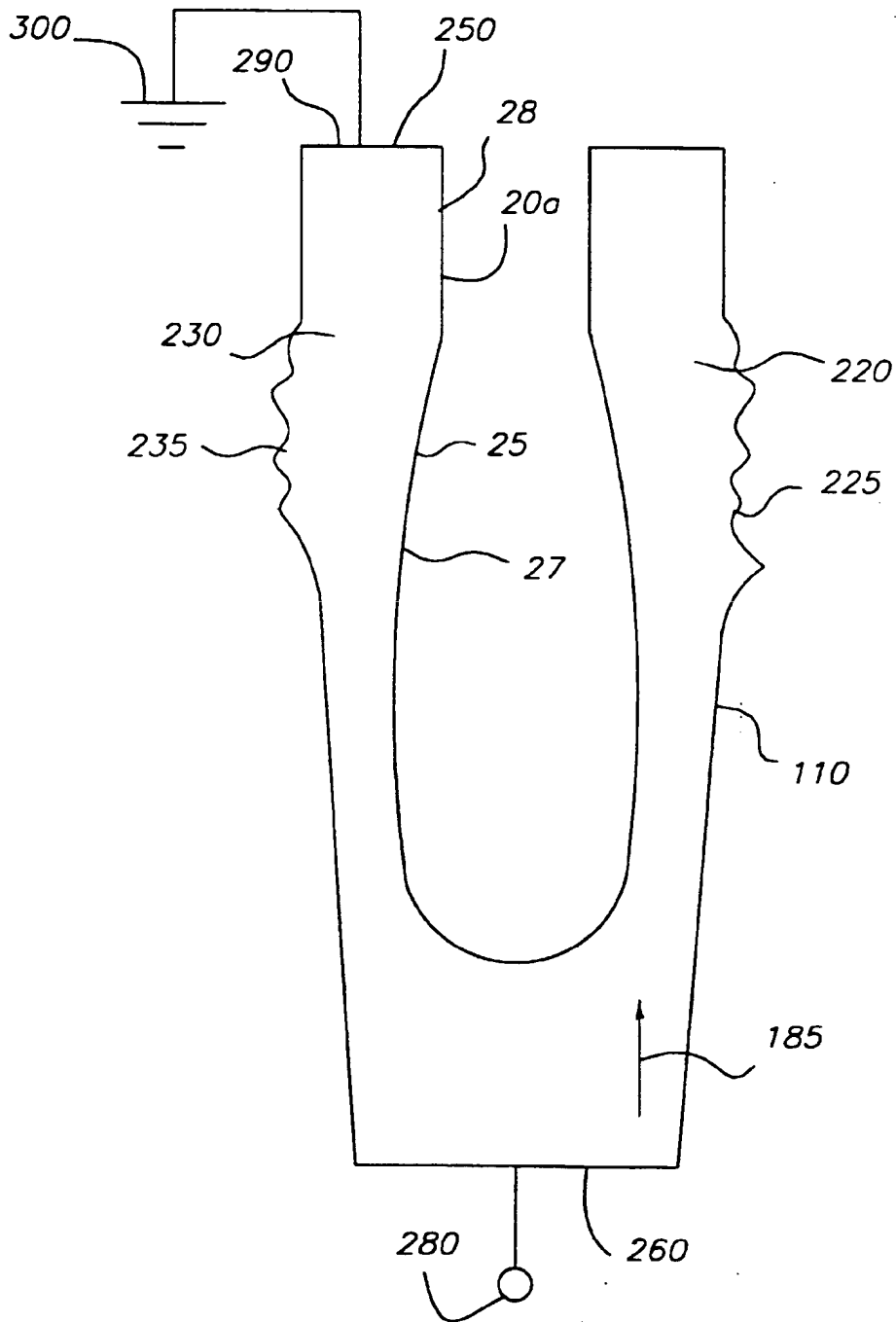


FIG. 13

